REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE Paper	3. DATES COVERED

4. TITLE AND SUBTITLE Systems Engineering Investigation of Navy Electrical Bomb Fuzing	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Gary A. Evans	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Air Warfare Center Aircraft Division 22347 Cedar Point Road, Unit #6 Patuxent River, Maryland 20670-1161	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Several recent campaigns have shown that conventional strike warfare demands electrical fuzed weapon systems satisfy a growing requirement for reliability. Additionally, the cost of delivery platforms and the weapons have experienced an upward trend that also places increasing demands on first strike lethality of weapons, survivability of the weapons and delivery platforms, and campaigns that result in rapid resolution. In order to optimize performance and meet these demands, weapon systems must perform reliably, even when considering operator intervention and training. Legacy United States Navy electrical fuzing systems have historically experienced reliability levels that required dual electrical/mechanical fuzing and/or multiple weapons to be assigned to disable/destroy a particular target. With the advent of new precision guided munitions based on legacy Mk 80 series bombs, the need to identify the factors that reduce electrical fuzing reliability in order to eliminate or minimize them is paramount. To identify these reliability factors, a full system engineering investigation of the elements that effect electrical fuzing reliability has been conducted on the F/A-18 aircraft, its legacy electrical fuzing system and general-purpose bombs, laser guided bombs, and JDAM. This paper presents test results and data analysis utilized to conduct the Navy electrical fuzing systems engineering analysis. Emphasis was placed on utilizing existing component, subsystem, and operational test data to efficiently identify the cause of electrically fuzed bomb duds.

15. SUBJECT TERMS

electrical bomb fuzing

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Gary Evans
a. REPORT	b. ABSTRACT	c. THIS PAGE		14	19b. TELEPHONE NUMBER (include area code) (301) 342-6959

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18

Systems Engineering Investigation of Navy Electrical Bomb Fuzing

Gary A. Evans (Naval Air Warfare Center, Patuxent River, Maryland)

Abstract

Several recent campaigns have shown that conventional strike warfare demands electrical fuzed weapon systems satisfy a growing requirement for reliability. Additionally, the cost of delivery platforms and the weapons have experienced an upward trend that also places increasing demands on first strike lethality of weapons, survivability of the weapons and delivery platforms, and campaigns that result in rapid resolution. In order to optimize performance and meet these demands, weapon systems must perform reliably, even when considering operator intervention and training. Legacy United States Navy electrical fuzing systems have historically experienced reliability levels that required dual electrical/mechanical fuzing and/or multiple weapons to be assigned to disable/destroy a particular target. With the advent of new precision guided munitions based on legacy Mk 80 series bombs, the need to identify the factors that reduce electrical fuzing reliability in order to eliminate or minimize them is paramount. To identify these reliability factors, a full system engineering investigation of the elements that effect electrical fuzing reliability has been conducted on the F/A-18 aircraft, its legacy electrical fuzing system and general-purpose bombs, laser guided bombs, and JDAM. This paper presents test results and data analysis utilized to conduct the Navy electrical fuzing systems engineering analysis. Emphasis was placed on utilizing existing component, subsystem, and operational test data to efficiently identify the cause of electrically fuzed bomb duds.

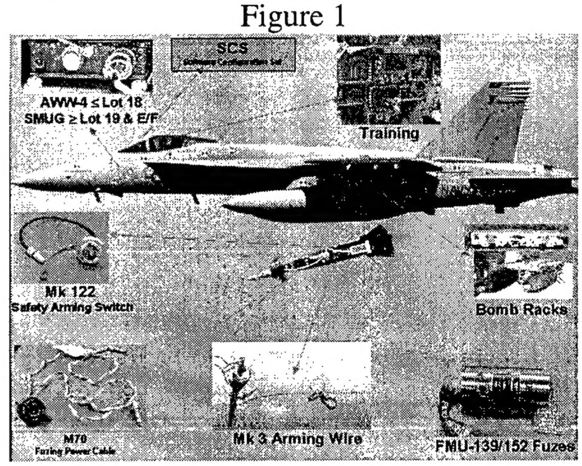
Introduction

The US Navy, in an effort to identify the root cause of dud electrically fuzed bombs, commissioned an electrical fuzing systems engineering evaluation. The study analyzed the electrical fuzing components, their specifications, operating histories, and interaction into the sub systems that comprise the aircraft/weapon electrical fuzing system. Navy experts for each of the components that make up the electrical fuzing systems focused their efforts into a systems engineering analysis vice a component level analysis.

Electrical Fuzing System

The current electrical fuzing system is comprised of several components. Some of these components are approaching 30 years in age with their specifications preceding them by 10 years. The major components of the electrical fuzing system are illustrated in figure 1.

Figure 1



The systems engineering analysis was conducted by dividing the system into two major subsystems comprised of the aircraft and the weapon.

The aircraft subsystems included:

- Aircraft Software
- AWW-4 Fuze Function Control Set (FFCS) F/A-18 Lot 18 and below
- F/A-18 SMUG Lot 19 and above
- Aircraft Wiring/Connections/Decoders
- Bomb Racks - BRU-32 and BRU-33
- CADS - CCU-45
- S-1 Bomb Rack Electrical Fuzing Switch

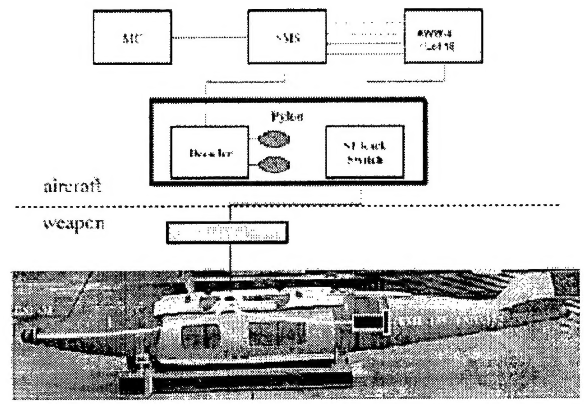
The weapon subsystems included:

- Mk 122 Safe Arming Switch
- M70 Bomb Cable Assembly
- FMU-139 Fuze
- FMU-152 Fuze
- Bomb Tail Sections
- Mk 3 Arming Wire
- DSU-33

Existing and new test data were reviewed and evaluated to identify the interaction of the components at the subsystem and systems levels. Figure 2 shows the interaction of the basic subsystems of the electrical fuzing system. Installed system data were compared to component and system interface specifications. Data utilized in this analysis included:

- Conventional Ordnance Performance Evaluation (COPE) Data
- Conventional Ordnance Deficiency Report (CODR) Data
- JDAM DT, OT, Operational Data
- Joint Programmable Fuze DT/OT
- DSU-33B/B First Article Acceptance Test
- Naval Aviation Logistics Data Analysis (NALDA)

Figure 2
Electrical Fuzing Component Layout



Aircraft Software

The F/A-18 A-D software analysis identified that early aircraft software Operational Flight Program (OFP) 89A installed in F/A-18A/B Lot IX and below aircraft, contained an error. This error could cause electrically fuzed bombs to dud in either the single or multiple releases mode. This error was also manifested in early versions of OFP 92A. A fix was available to the fleet in Jan 1995 that corrected this deficiency. All OFP loads subsequent to 92A and 91C undergo a testing process to preclude an error similar to this from recurring.

As part of this systems engineering investigation, all operational software loadings for the F/A-18 were verified in lab ground tests. The operation of both the AYQ-9 w/AWW-4 and AYK-22 (SMUG) were tested. Single and multiple release mode combinations were evaluated for general purpose (GP) Bombs, Laser Guided Bombs (LGBs), and Joint Direct Attack Munitions (JDAM). Manual, target of opportunity (TOO), constant computed impact point (CCIP), and AUTO modes were verified to provide the specified outputs in all relevant delivery modes. No anomalies were identified and in all tests the electrical fuzing signal provided was within

specified limits and of a sufficient duration and magnitude to fully arm the fuze. Figures 3 and 4 show software test data for the JDAM electrical fuzing signal. Both figures 3 and 4 indicate that the proper electrical fuzing signal was present prior to the bomb rack CAD firing. Sufficient signal remained until after the Mk 122 co-axial connecter was extracted from the bomb rack connector.

Figure 3
Aircraft Software Data Sample

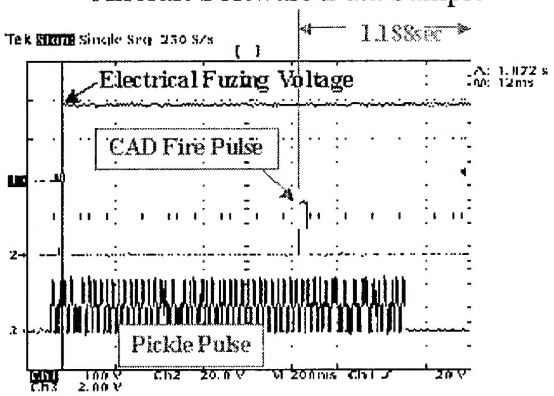
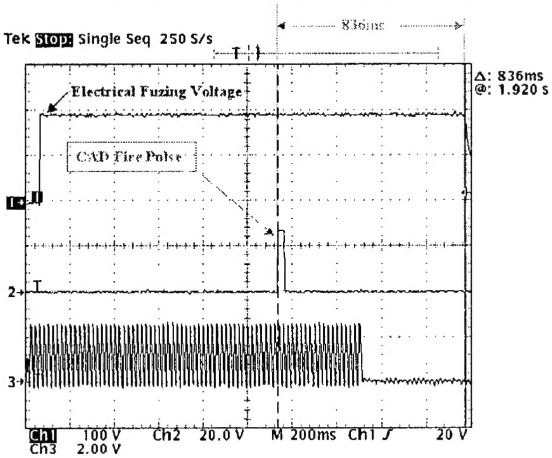
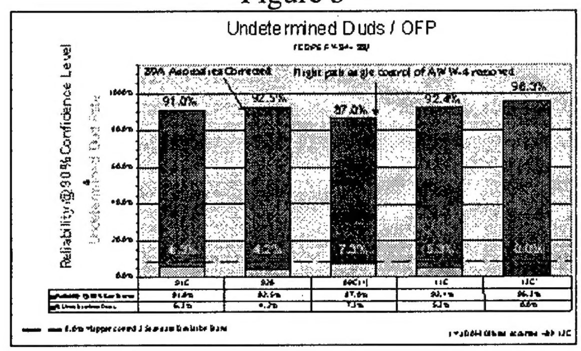


Figure 4
AYK-22 Electrical Fuze Timing Data
JDAM on BRU-32, TOO release



In order to compare the ground laboratory results with installed system data, fleet training data from the Conventional Ordnance Proficiency Evaluation (COPE) Program were analyzed from single electrically fuzed bomb releases over a period of six years subsequent to the OFP fix. These data shown in figure 5, relate the undetermined dud bomb releases with the aircraft software present in the releasing aircraft. These data were then correlated with the software updates. This analysis identified that no correlation existed between unknown dud bomb rates and aircraft software changes. These operational data agree with the lab test results.

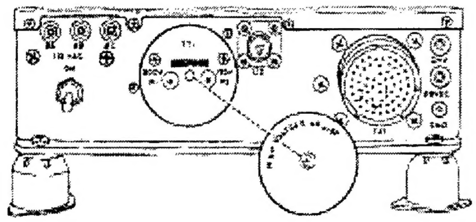
Figure 5



AWW-4 Fuze Function and Control Set (FFCS)

The AWW-4, Figure 6, provides electrical fuzing power to the fuze via several safety interlock devices. It is used in F/A-18 Lot 18 and below aircraft. Its mean time between failure (MTBF) rate was found to far exceed its specification. It has a record in the F/A-18 aircraft of over 2000 flight-hours/maintenance action for a recent 3-year period while only specified for a MTBF of 1000 hours. Its power output is specified at 500ma, which is powerful enough to provide an arming signal to several weapons simultaneously.

Figure 6
AWW-4



Lot 19 and above aircraft have incorporated the power function of the AWW-4 into the Stores Management Processor (SMP) during the Stores Management Upgrade (SMUG). Historically in Navy aircraft such as the A-6, the AWW-4 provided one second of electrical fuzing power after the release of the bomb consent "pickle" switch. The F/A-18 aircraft however controls this one-second power via software. Earlier versions of aircraft software provided a shorter than one second power-on signal after pickle release. This was found not to have an adverse effect on fuze capacitor charge time or bomb duding. Current OFPs provide a longer power-on time after pickle release to ensure the bomb will dud as expected via internal FMU-139 arming logic if the store hangs on the bomb rack. COPE data identified that increasing the duration of the electrical fuzing signal length had no effect on bomb dud rate. This can also be confirmed by comparing bomb ejection velocities to the charge time permitted by the Mk 122 fuze safety switch. The Mk 122 fuze safety switch disconnects power from the fuze long before the aircraft software removes power.

AWW-4 and wiring malfunctions were also evaluated. The F/A-18 does not currently perform a built in test (BIT) to verify the AWW-4 is functioning properly. This has the potential to allow an electrically fuzed bomb to be released unarmed if an unknown malfunction is present. Current electrical fuzing checks for available power at the bomb rack are not required unless an extended period of electrically fuzed bomb drops is to be conducted.

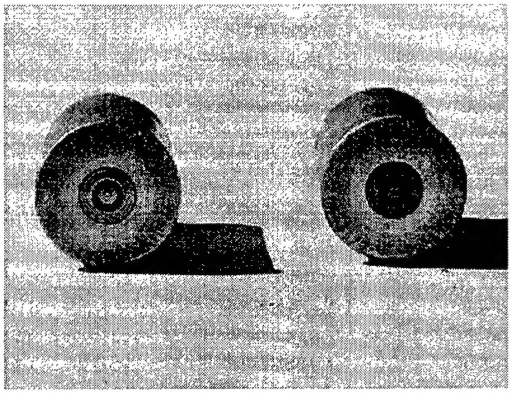
Momentary Short Circuits

One differences found between the AWW-4 and the SMUG SMP was short circuit recovery time. The ability of the AWW-4 to recover from a transitory short circuit was less than 2 milliseconds (ms) while the SMUG SMP found in current production F/A-18 aircraft is greater than 10ms. This was not a requirement that was specified for either the AWW-4 or the SMUG. A transitory short circuit condition can occur with an out of tolerance Mk-122 Safety Arming Switch. This can happen when the switch stab plunger penetrates the EMI shield if the insulation on the plunger is not of the specified length. Only one instance of this has been documented in several hundred ground tested switches. The 10ms short was not long enough to dud a 1000 or 2000 lb bomb by itself on a parent station. Because of the increased ejection velocities it could dud a 500 lb bomb on a parent station or a 500/1000 lb bomb on a Canted Vertical Ejector Rack (CVER).

CADS

As part of the systems engineering evaluation, the effect of CCU-45, Figure 7, and delayed ignition was analyzed to determine if it could contribute to electrical fuze duds. Lot and random sampling test data were compared to CAD performance specifications. Lot tests indicated CCU-45s are performing within the specification.

Figure 7
CCU-45 CADS



Data analysis from several hundred F/A-18E/F weapon releases using CCU-45s also did not identify any problems. This was verified by subtracting the bomb rack operation time from the CAD spec values shown in Table 1, which contains the CCU-45 specifications. Ignition delay time plus bomb rack ejector piston end of stroke was less than 110ms in all cases for Mk 82, 83, and 84 bombs.

Table 1
CCU-45 Performance Specifications

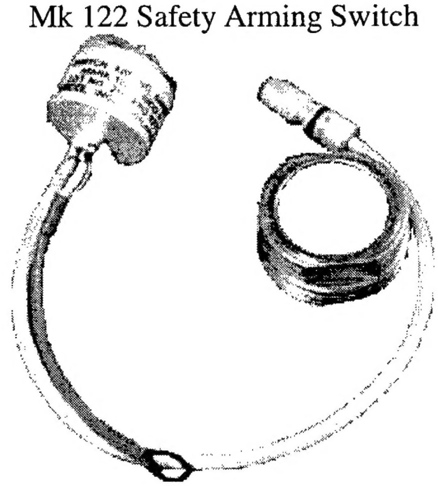
Ignition delay time	< 10ms
•Time to max pressure	< 5ms
•Time to max thrust	< 40ms
•Thrust	> 5,000 lbf
	< 8,000 lbf
•Velocity	> 23 ft/sec
	< 31 ft/sec

Therefore, lot and random sampling tests of CCU-45s have not identified any CCU-45 reliability issues related to electrically fuzed bomb dud rate. Ignition delay time alone would need to be in excess of 100 ms to have an impact on older OFPs (87D, 10A, 89A). Newer OFPs (13C and 15C) would require an ignition delay in excess of 700ms

Mk 122 Safety Arming Switch

The Mk 122 Safety Arming switch, Figure 8, was developed in the early 1960's. It transfers aircraft fuze power to GP bombs. It was developed when bombs were ejected with relatively low ejection velocities compared with modern bomb rack units (BRU) such as the BRU-32 on the F/A-18 and F-14. The Mk 122s were first produced in March of 1963 and the last lot was produced in 1975. The majority of the remaining inventory of switches was manufactured between fiscal years 1970 and 1973.

Figure 8
Mk 122 Safety Arming Switch



The Mk 122 controls the available power connect time to charge the capacitor's fuze by the difference in length between two cables, the arming lanyard and co-axial cable. The difference in length is a nominal 7.175".

The specifications for the Mk 122 require a switch closure time of 2.5ms after lanyard removal. Switch bounce is permitted but no

low resistance paths to ground (or short circuits) are allowed. The lanyard length is 5.875" +0.250/-0.188 and the Co-axial cable length is 13.050" +.000/-0.375. Several Aircraft/ Mk 122 interface factors were identified during this analysis that can reduce fuze capacitor charge time and contribute to or directly cause a bomb to dud.

- Co-axial cable routing
- Co-axial cable and lanyard tolerance
- Inventory age effects
- Rack and wing dynamics
- Momentary short circuit
- Increased delivery acceleration

Momentary short circuit was discussed in the AWW-4 paragraph and will not be repeated here. Increased delivery acceleration was analyzed and determined not to be a single source of dud bombs by itself. Increased acceleration deliveries however, combined with any of the above factors can greatly increase the chance of a dud bomb.

Co-axial Cable Routing Failures

Co-axial cable routing failures were identified during F/A-18E/F Engineering and Manufacturing Development (EMD) weapon separation testing. Post flight suspension equipment inspections found several instances of the Mk 122 co-axial cable returning with the aircraft after a weapon release. Figures 9 and 10 are post flight photos of the BRU-33 loaded on the F/A-18E/F. They identified two failure modes that are applicable only to the BRU-33 and Mk 82/83 bombs. The relative position of the BRU-33 rack lock/unlock handle to the co-axial cable of the Mk 122 coupled with flight air loads on the co-axial cable caused both of these failures. The air loads forced the cable against the side of the bomb rack unit. When the weapon is released the cable becomes hung-up on the bomb rack mechanisms. In figure 9 the cable became trapped between the rack lock/unlock handle and the positive arm latch handle. This hang-up reduces the effective length of the Mk 122 coaxial cable relative to the lanyard. This failure would significantly reduce the duration of the charge time and may cause a dud bomb. Figure 10 shows a similar but more serious failure mode where the co-axial cable was forced by air loads to loop around the rack lock/unlock handle. This failure would prohibit the fuze capacitor from receiving its required duration charge signal of 15ms and result in a dud bomb. The aircraft contractor performed original weapon integration testing on the F/A-18A. Weapon components such as the Mk 122 were thought to be irrelevant and thus this failure mode was never identified.

Figure 9
F/A-18E/F / BRU-33 Mk-122 Failure

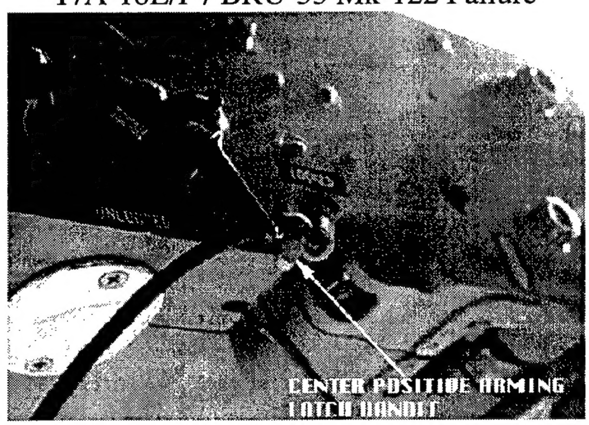
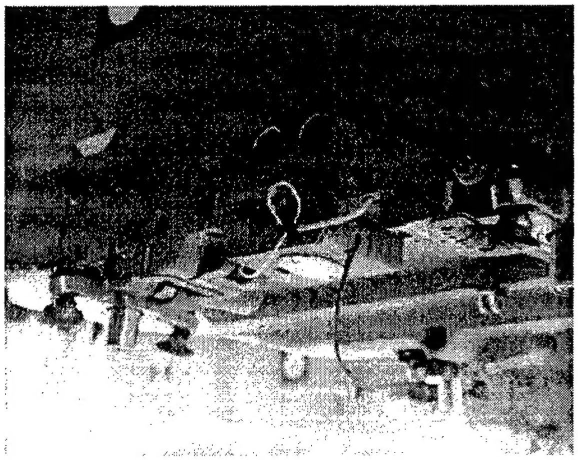


Figure 10
F/A-18E/F / BRU-33 Mk-122 Failure

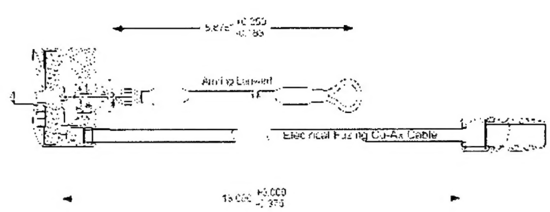


From careful post flight examination the F/A-18E/F EMD known failure rate for cable hang-up was 2.2% that equates to a 97.0% reliability at a 90% confidence level based on eight recorded failures out of a total of 361 recorded test events. The failures were split evenly between 500 and 1000 lb bombs (4/181 Mk 82 and 4/180 Mk 83). Navy weapon integration standard operating procedures (SOP) increased the chances of finding these failures. After a weapon separation flight, the delivery aircraft was required to directly return for post flight armament inspections. Subsequent data analysis of COPE data has reveled an F/A-18 A-D known failure rate of 1.5% which equates to a 97.8% reliability at 90% confidence levels were based on three failures out of 195 data samples. The failure rate is almost certainly much higher as the evidence is easily lost in flight or on landing. This can be seen by close examination of figure 9. The co-axial cable connector has been extracted from the BRU-33 electrical fuzing connector and is ready to fall out. Therefore, co-axial cable hang-up will cause electrically fuzed bomb failures. This failure mode as stated above is only applicable to the CVER with Mk 82 and Mk 83 bomb bodies. Mk 82 and Mk83 JDAM mounted on the BRU-33 or similar CVER type rack configured with an Mk 122 will be susceptible to the same failure modes. Alternate cable routings may eliminate or reduce these failures.

Mk 122 Co-Axial Cable and Lanyard Tolerance

Fuze charge time can be adversely effected by the specified tolerances figure 11, of the lanyard and co-axial cable. Fuze charge time is directly related to the difference between the arming lanyard and co-ax cable length a nominal 7.175". The original tolerances were developed for low ejection velocities. Current operational bomb racks have higher ejection velocities and reaction loads. The worst case occurs with the longest lanyard and shortest co-axial cable. The co-axial cable tolerance allows the cable to be up to -0.375" shorter. The arming lanyard tolerance allows the cable to be up to +0.250" longer. Stacking these worst-case tolerances yields a worst-case tolerance stack of 0.625 inches. This tolerance stack can decrease available fuze capacitor charge time by as much as 10% (2.4ms) based on an Mk 82 nominal ejection velocity of 22ft/sec. Fifteen milliseconds are required for full FMU-139 charge. Therefore a limited margin exists in the current switch design for high ejection velocities [or rack dynamics].

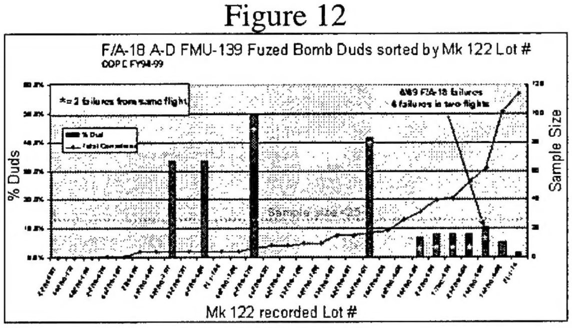
Figure 11
Mk 122 Switch Arrangement



Mk 122 Inventory Age

The majority of Mk 122 inventory is almost 30 years old. Switch function may be impaired by lubricant used in the switch that has degraded and migrated into areas of the switch it was not intended for. Original tests designed to verify the switch performance are no longer valid due to sticking brought about by age. Limited on-aircraft F/A-18 & AV-8B ground tests of two switch lots identified switch closure times in excess of the specification time of 2.5ms. Mk 122 Lot FII was greater than 4-5 ms and Lot TMC was greater than 7-7.5 ms. Switch delays reduce fuze charge time margin. Analysis of COPE data, figure 12, did not identify any particular critical lots of Mk 122 Safety Arming Switches.

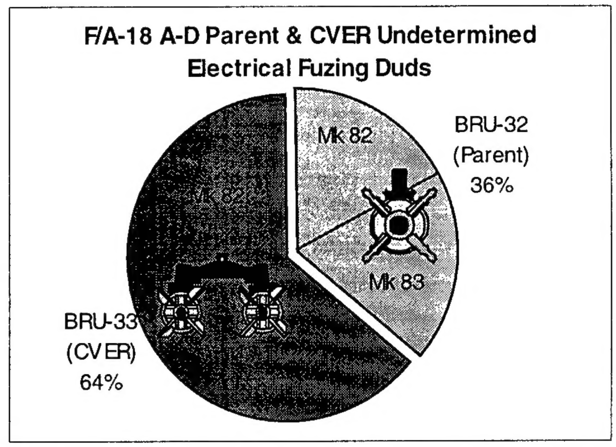
Figure 12



BRU-33 CVER Ejection Dynamics

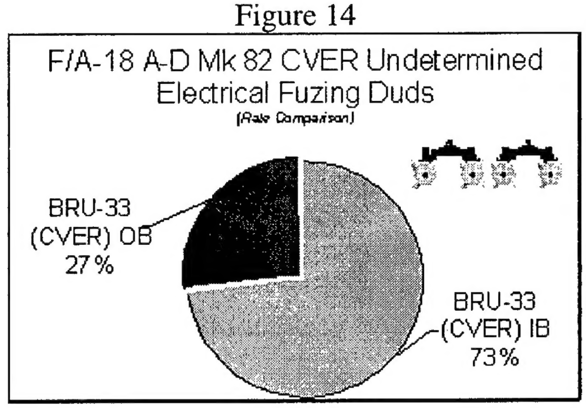
The BRU-32 and BRU-33 have some of the highest ejection velocities of current operational Navy bomb racks. From the analysis of Navy COPE data, figure 13, it was determined that 64% of the F/A-18 undetermined duds occurred when bombs were released from the CVER. Parent station undetermined duds were evenly split between Mk 82 and Mk 83 bombs. The COPE data sample for CVER was made up mainly of 500lb Mk 82 Bombs.

Figure 13



The largest percentage of undetermined duds from the CVER occurred from the inboard CVER station, figure 14 that is the second bomb to be released from the CVER.

Figure 14



The CVER ejection dynamics are the greatest when only one store is loaded on the CVER as shown in figure 15. Ejector piston reaction loads force the CVER to pivot away from bomb as seen in figure 16. The reaction loads pivot the BRU-33 to an elevated displacement after the first bomb has already been released. In this configuration a roll rate is also imparted into bomb by the BRU-33 ejector feet. The combination of these dynamics shortens the time between lanyard pull and umbilical disconnect.

Figure 15

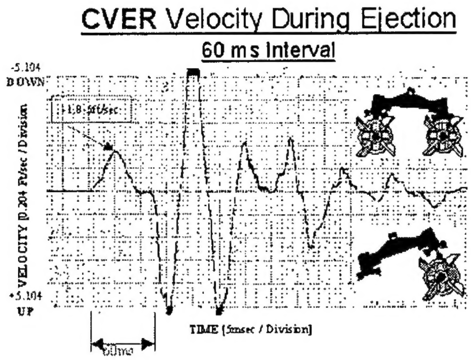
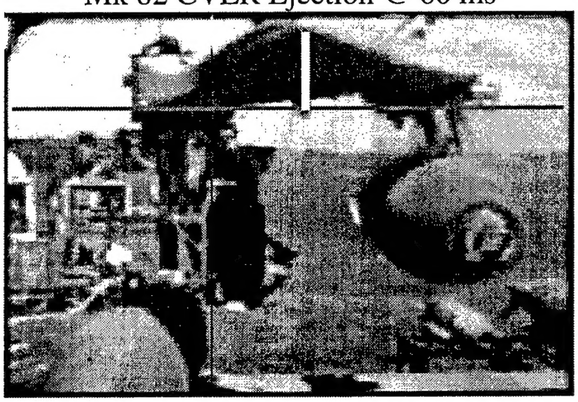


Figure 16
Mk 82 CVER Ejection @ 60 ms



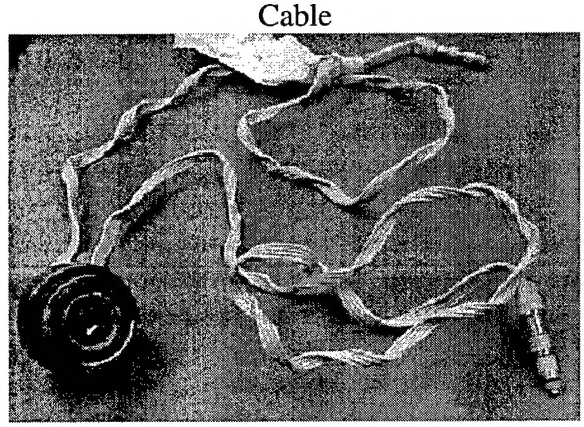
It can also be shown from ground test data that CVER ejection dynamics change as a function of the release interval. The combination of CVER ejection dynamics and the roll rate imparted into the bomb reduce the Mk 122 co-axial cable connect time to the point where a bomb dud can occur for both 500 and 1000lb bombs on the CVER.

In summary the existing aging inventory of Mk 122s are still acceptable for the ejection velocities and aircraft interfaces they were originally designed for. The switches however, have minimal margin left for current high ejection velocities coupled with rack dynamics present with CVER type suspension equipment.

M-70 Cable

The M70 cable, figure 17, is routed inside Mk 80 series GP bomb body conduits. The cables are installed when the bombs are manufactured. Its purpose is to pass FFCS power from Mk 122 switch to the fuze. Testing of the cable prior to bomb assembly was discontinued due to high reliability. The only identified weak link was the cable spring clip / fuze interface, but no data exists to determine if this connector is presently contributing to the undetermined dud rates. As the inventory of bombs age, the potential for corrosion on connectors increases. Limited random sampling of test assets did not identify any problems. Therefore, the M70 cables at this time are not thought to be a significant contributor to electrically fuzed bomb duds.

Figure 17
M70 Bomb
Cable



FMU-139

The FMU-139 Electrical Bomb Fuze, figure 18 requires 15 ms of fuze function control set (FFCS) power to arm. It has been verified to function with less than the specification charge time, but its reliability is based on a full charge of 15 ms and without this it may not meet the specification operating life of 60 seconds. Most of the fuze power is used to reach arm time. Some

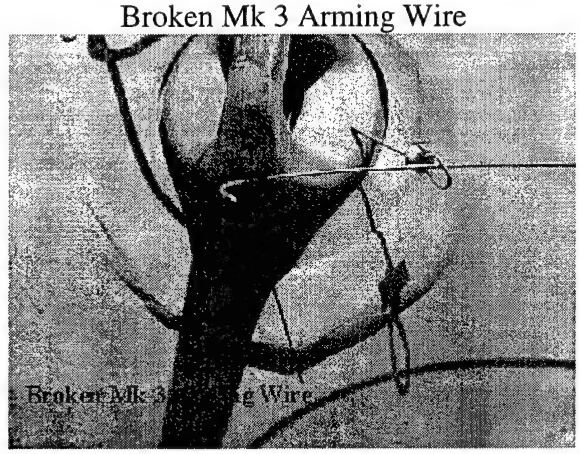
power is used after Arm Time is reached. The fuze capacitor is specified to have a 95mA max current draw. Tests have identified 80mA are typical. The fuze reliability specification is 95% reliability at a 90% confidence level. Based on Navy bench tests the fuze has demonstrated a 98.3% reliability at a 90% confidence level well above the specified value. These tests however were performed without the booster installed. Controlled aircraft flight tests performed by the U.S. Air Force also show the FMU-139 to exceed the specification at 97% reliability at a 90% confidence level. Therefore, when the fuze is given the proper minimum required charge profile and duration of 15 ms both the Navy and Air Force experienced similar reliability at a 90% confidence level using different test methods.

Figure 18
FMU-139 Electrical Bomb Fuze

Mk 3 Arming Wire
The Mk 3 arming wire is used to prevent the electrical fuze from arming before the store is released. It is known to have several failure modes that have caused dud bombs. The last Mk 3 lot was procured in the early 1960's. Remaining inventory wires appear to be marginal in strength and ductility. Material of some lots were tested and found not to meet the required specifications.

Random sampling of Mk 3 wire material reveled a carbon steel of 0.88-0.94% C, and not the specified age hardening steel AMS-355.
Several bomb failure modes have been attributed to the Mk 3 arming wire. First, the routing of the arming wire around the bomb lug makes it susceptible to damage if it becomes jammed between bomb rack hook and lug during loading, in-flight carriage, separation, and downloading as shown in figure 19.

Figure 19
Broken Mk 3 Arming Wire



Another failure mode of the Mk 3 arming wire occurs when used in conjunction with the Mk 82 BSU-86 Tail Fin. The fin blade movement of the BSU-86 can cut or kink the wire during carriage as shown by figure 20. This failure mode has also been reported on Mk 15 fins.

Figure 20
Crimped Mk 3 Arming Wire on BSU-86 Fin

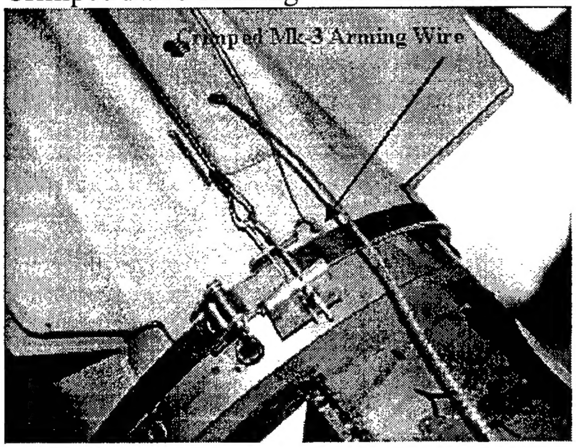
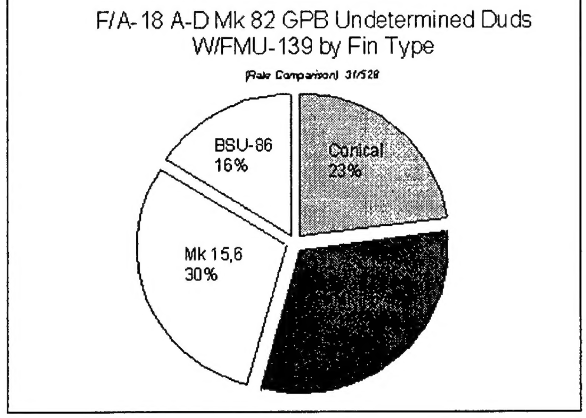
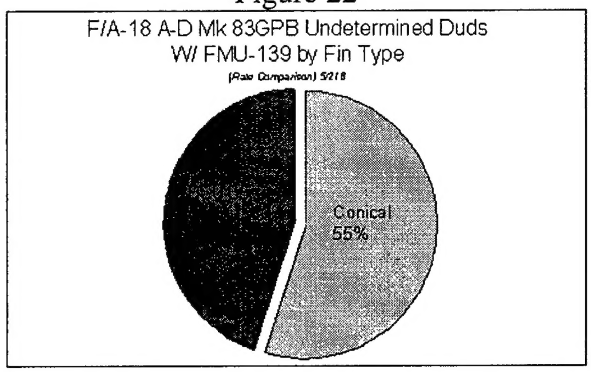


Figure 21



In flight cyclic fatigue is another known failure mode. Air loads on the wire causes cyclic fatigue. In summary, failures of Mk 3 arming wire certainly contribute to the undetermined dud rate. The actual rate of failure however cannot be determined from existing data because the bombs were not recovered and inspected.

Figure 22

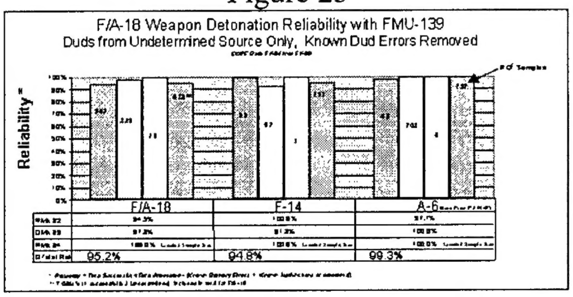


Bomb Tail Sections
The effect of different bomb tail sections was also analyzed as part of the investigation. Undetermined dud rate data was correlated by bomb tail section for Mk 82 bombs figure 21 and Mk 83 bombs figure 22. From this undetermined dud rate data it was determined that any major source of unknown duds seem to be independent of fin type. BSU-86 and Mk 15 fin wire failures caused by fin blade movement do not appear to be excessive from training flight profiles that this data is taken from.

Failure Analysis
Weapon reliability data from the Conventional Ordnance Performance Evaluation (COPE) program and Conventional Ordnance Deficiency Report (CODR) were used in this analysis. Six years of data FY94-FY99 were compiled and correlated to determine weapon system reliability, which includes both the aircraft and the weapon. This analysis includes data for FMU-139 fuzed weapons only. Figure 23 shows COPE dud rates from undetermined sources only. The data shows that the F/A-18 and F-14 have a similar reliability, during this period in training, of approximately 95% (same as the fuze specification). The A-6 had a significantly higher reliability during this period. Several factors may contribute to this perceived

higher reliability rate for the A-6. First, the sample size is for the A-6 was limited. Second, the data were older encompassing only two years (FY94 and 95) and the A-6 was a two-aircrew platform. Finally, delivery airspeeds were lower and the ejection velocities were lower. From the COPE data only the F/A-18 sample size for Mk 82 and Mk 83 single E-fuzed bombs which was greater than 800 was sufficient for additional analysis.

Figure 23



The F/A-18 COPE data set were first verified to ensure they fit within the 3-sigma control limit constraints, figure 24. From analysis of the F/A-18 COPE data, the duds were split into three categories as depicted in figure 25. The first of the categories, known delivery errors, had a 3.5% delivery error rate. The second category, known hardware malfunctions, had a 4.3% hardware failure rate. The third category, undetermined dud sources, had a 4.4% undetermined dud rate.

Figure 24

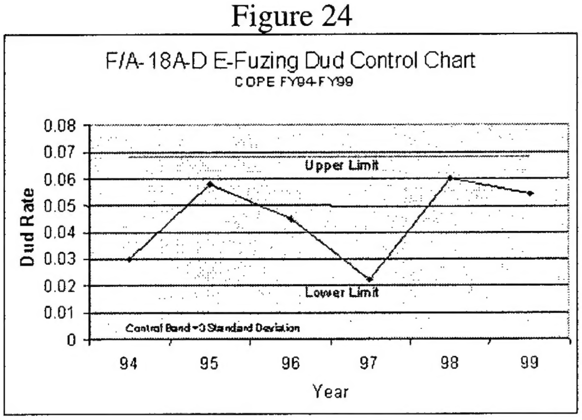
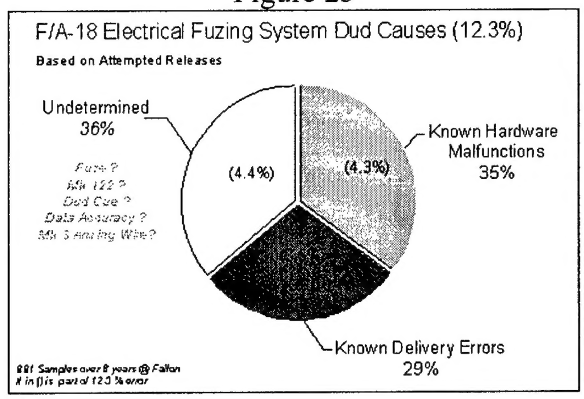


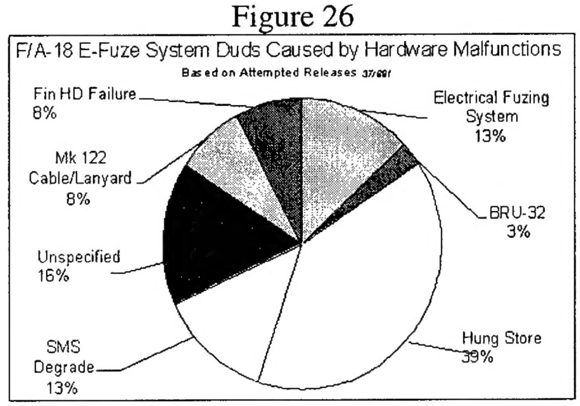
Figure 25



Hardware Malfunctions

Hardware malfunctions were reviewed and sub divided into categories in figure 26. A few of these subcategories require further amplification. As previously stated Mk 122 cable/lanyard failure evidence is easily lost after weapon release in a test environment and even more so in an operational scenario. It is suspected that this failure occurs more frequently and is contained in the 4.4% undetermined dud category. Next, of the reported hung stores, 87% occurred in one Fiscal year, (FY 98) and 53% were attributed to two aircraft. Finally, of the majority of the SMS degrades, 80% occurred on the same acft.

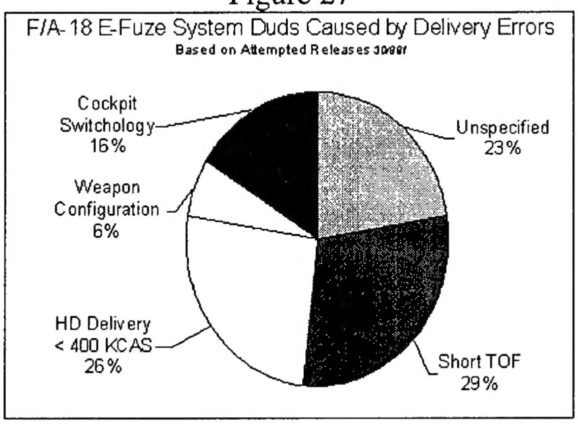
Figure 26



Delivery Errors

Delivery errors were reviewed and separated into categories in figure 27. Short time of fall (TOF) and delivery of high drag weapons at less than 400 KCAS account for the majority of delivery errors. Short TOF duds can occur prior to receipt of a dud cue. A dud cue is displayed on the heads up display (HUD) when the fuze arm time is greater than the aircraft calculated weapon time of fall. The time of fall for dud cue generation however does not account for fuze arm time tolerances. Therefore a short TOF dud can occur even though no dud cue is generated.

Figure 27



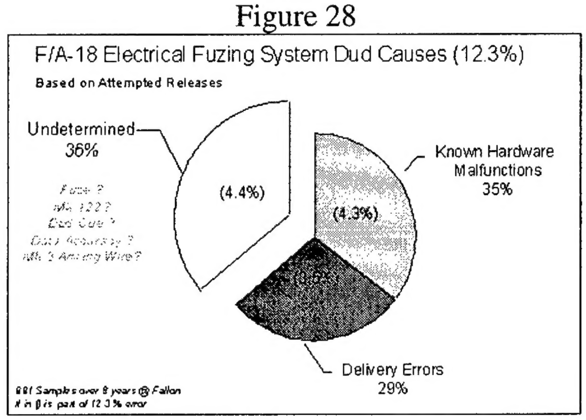
Unknown Duds

As discussed earlier many unknown duds may result from existing known hardware malfunctions and delivery errors. From the COPE and CODR data analysis several common factors were found linking unknown duds. Almost half, 46%, of the unknown duds occurred on aircraft with two or more duds on the same flight. Seven aircraft had two failures on the same flight, which accounts for fourteen of the unknown duds. One aircraft had four failures on the same flight releasing four dud bombs. As previously discussed, the Mk 3 arming wire and fuze failures cannot be extracted from the COPE or CODR data because the bombs were not recovered and examined. Therefore, any unknown "Root Cause" failure mechanism must share the 4.4% unknown DUD category with the above anomalies. If the FMU-139 Navy reliability test data of 6 failures out of 605 samples or a 98.3% reliability at a 90% confidence level were extrapolated to the Cope Data sample size it should contain approximately 8 failures. In summary, there is little room left for a major unknown failure mode in the electrical fuzing system.

Conclusion

The F/A-18A thru D aircraft electrical fuzing system is at least 95% free of unknown failures. Zero to 4.4% of F/A-18 duds could be attributed to an unknown failure mechanism; however, it is highly unlikely. There is a high probability that the majority of the 4.4% of unknown failures depicted in figure 28 fit known hardware or delivery failure modes. Hardware issues such as fuze failures, Mk 122 cable routing, rack dynamics, tolerances, aging, and Mk 3 arming wire breakage combined with known delivery errors - too slow, time of fall, and dud cue tolerances leave little room left for any serious unknown root cause failure mechanisms to exist.

Figure 28



Full systems tests to characterize in flight electrical fuzing performance have never been conducted on the F/A-18 due to the perceived high cost. Testing of weapons in the operational configuration with functional hardware can identify problems early. This is not often done due to the cost during developmental testing. Most of the causes of electrically fuzed dud bombs found in this study could be identified by a full systems evaluation prior to operational deployment. Operational data gathered from programs such as the COPE program is indispensable when completing a systems engineering evaluation.

Author Biography

Mr. Gary Evans is a senior aircraft/weapon compatibility engineer with the Test and Evaluation Engineering Department of the U.S. Naval Air Systems Command at Patuxent River, MD. Mr. Evans is currently employed as the Lead US Navy Weapon Certification Engineer on the Joint Strike Fighter. From 1994 to 1999 he served as the F/A-18 E/F Weapons Integration Team Leader. Since 1988 Mr. Evans has conducted both conventional and nuclear weapons integration testing on the F/A-18E/F, F/A-18A-D, A-6, A-4, F-4, P-3 and S-3 aircraft. Mr. Evans has a Bachelor of Science degree in Aerospace Engineering from the Pennsylvania State University and holds a commission in the United States Navy Reserve as an Aerospace Engineering Duty Officer.